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# Resolving the Outer Disks and Halos of Nearby Galaxies

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In a hierarchical merging scenario, the outer parts of a galaxy are a fossil record of the galaxy's early history (e.g. [1]). Observations of the outer disks and halos of galaxies thus provide a tool to study individual galaxy histories and test formation theories. Locally, an impressive effort has been made to understand the halo of the Milky Way, Andromeda, and M33 (e.g. [9, 4, 6] and contributions in this volume). However, due to the stochastic nature of halo formation, a better understanding of this process requires a large sample of galaxies with known halo properties. The GHOSTS<sup>3</sup> project (PI: R. de Jong) aims to characterize the halos and outer portions of 14 nearby ( $D=4-14$  Mpc) spiral galaxies using the Hubble Space Telescope. Figure 1 shows the type, rotation velocity and inclination of all 14 galaxies. Detection of individual stars in the outer parts of these galaxies enables us to study both the morphological properties of the galaxies, and determine the stars' metallicity and age.

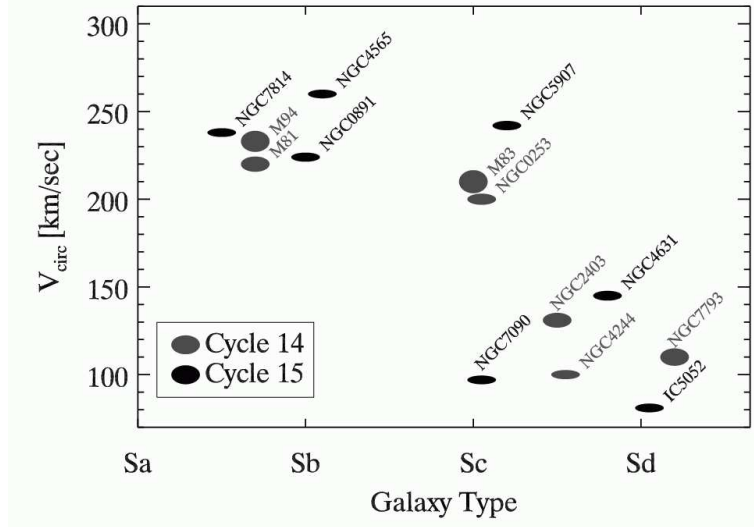
## 1 Disk and Halo Profiles

The GHOSTS data consists of  $\sim 6$  ACS or WFPC2 fields in each galaxy, primarily distributed along the major and minor axes (see Fig. 2). This areal coverage allows us to characterize the shape of the outer disk and halo components, especially in the eight edge-on galaxies in our sample where disk and halo components can be easily separated. Using individual stars, we can trace out the number density profile down to equivalent  $i_{AB}$ -band surface brightnesses of  $\sim 31$  mag/arcsec<sup>2</sup>. We discuss here two initial results on the disk and halo profile of NGC 4244.

The edge-on galaxy NGC 4244 is a low mass ( $V_{rot} \sim 100$  km/sec), SAcD galaxy, similar to local group spiral M33. The GHOSTS data is shown in Figure 2, with a CMD of one of the outer disk fields showing the richness of the stellar populations detected in our data. In addition to the prominent red

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<sup>3</sup> GHOSTS = Galaxy Halos, Outer disks, Streams, Thick disks, and Star clusters

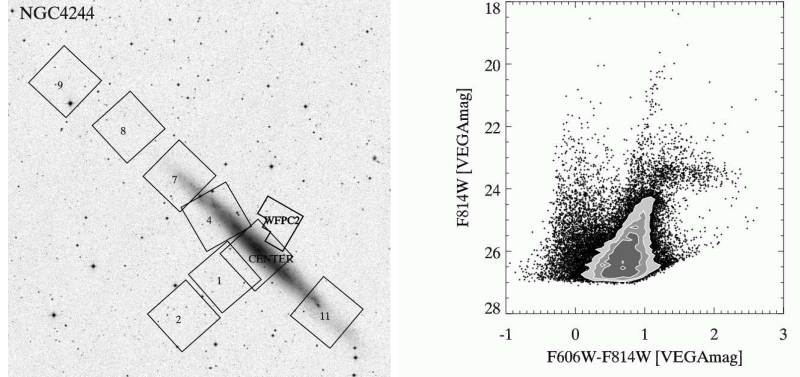


**Fig. 1.** The galaxy type vs. the circular velocity for the GHOSTS sample of galaxies. Shape of the circle indicates the inclination of the galaxy. Gray points were part of the Cycle 14 snapshot project, black points are part of the Cycle 15 large project.

giant branch (RGB), smaller numbers of young main sequence and helium burning stars (MS) and asymptotic giant branch stars (AGB) are seen. These populations cover the entire history of the galaxy (see [11]).

Along the major axis, we find that the disk exhibits a strong truncation at a radius of  $\sim 420''$  (see [2] for details). Such truncations or breaks in the surface density profile are commonly observed in disk galaxies, but we are able to resolve the stellar populations across a truncation for the first time. Interestingly, the break occurs in the same location for all of the stellar populations from young to old. Also, the break occurs at the same radius for populations located above the midplane of the galaxy as well. These results show that the break radius in this galaxy has been roughly constant over time, thus favoring dynamical mechanisms for producing the break (e.g. [3]) versus star formation threshold mechanisms (e.g. [7]).

The minor axis of NGC 4244 is also very interesting. As noted in [11], the scale height of the old RGB population is higher than the younger stellar populations. With the GHOSTS data, we are able to trace this RGB profile out to  $\sim 10$  kpc ( $\sim 30$  scale heights) above the plane (see [12] for details). The exponential profile seen in our original data gives way to a slower decline above  $\sim 2.5$  kpc. If fit to an exponential, this more diffuse component has a scale height similar to the scale length of the main NGC 4244 disk, suggesting that we are detecting a spheroidal halo. Despite being very tenuous, this halo appears to be more massive than the halo expected for such a low-mass galaxy [10].



**Fig. 2.** *Left* – Numbered fields show the GHOSTS data for NGC 4244. Other archival HST data is also shown. *Right* – The color-magnitude diagram of field number 7 containing more than 20,000 stars. The contours outline the RGB component, with the younger MS and AGB components creating the other features.

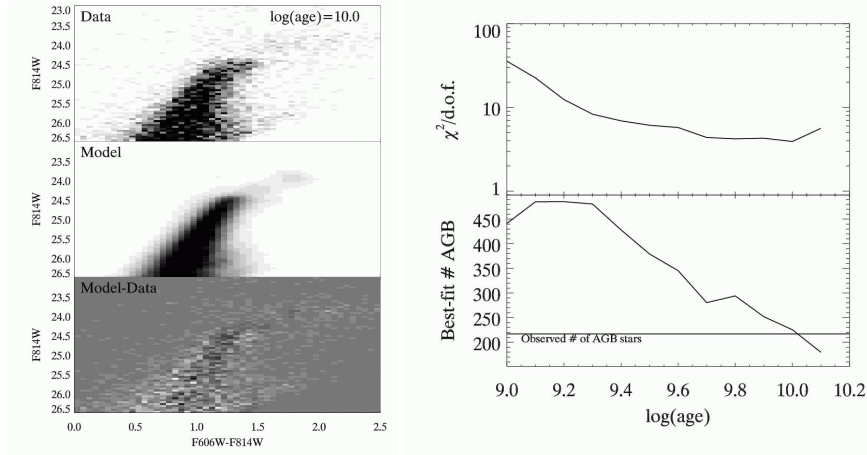
## 2 Metallicity and Age information

The metallicity distribution of stars in the halos of galaxies provides information on the mass of the galaxies which were shredded to make the halo. The color of individual RGB stars depends primarily on their metallicity, and therefore is commonly used to derive the metallicity distribution.

We have considered two different methods for constructing metallicity distribution functions (MDFs). First, we interpolate each individual star in our CMD onto a grid of isochrones assuming an age of 10 Gyr. From this, we have found that a majority of the GHOSTS fields have MDFs that peak at  $[Z] \sim -0.7$ . This occurs in both fields which are apparently dominated by stars in the outer disk and others which appear to be halo-dominated.

While the interpolation method is roughly correct, the photometric errors translate into asymmetric errors in the metallicity and the contribution of AGB stars below the tip of the RGB is ignored. These uncertainties particularly affect the metal-poor end, preventing us from determining if these stars are present.

To try improving on this method we are using CMD fitting techniques in which model CMDs of a given age (including both RGB and AGB stars) are convolved with realistic errors. As an example of this method, we present results from our observations of a prominent stellar stream in M83 at a projected distance of  $\sim 25$  kpc from the galaxy center. Using the Starfish code [5] and Padova models with updated AGB tracks [8], we fit the CMD of this field to a series of models at different ages. The CMD of the stream and the best-fitting model is shown in Figure 3. This model has a peak metallicity of  $[Z] = -0.5$ , suggesting the stream is quite metal-rich. Furthermore, the AGB



**Fig. 3.** *Left* – Hess diagrams of the M83 stream data, the best-fitting 10 Gyr model, and residuals. *Right* – The best-fitting models’ reduced  $\chi^2$  and number of AGB stars versus age. The AGB stars are significantly overproduced at ages younger than 5 Gyr.

stars provide us with the possibility of constraining the age of the stream. The right side of Figure 3 shows the reduced  $\chi^2$  of the best-fitting model vs. age. Clearly models with ages larger than 5 Gyr are favored, primarily because models with younger stars significantly overproduce AGB stars.

*Conclusions:* The GHOSTS survey is providing information on the shape and metallicity of the halos and outer disks of 14 nearby galaxies. We have presented initial results on the major- and minor-axis profiles of NGC 4244 and the metallicity and age of the stream in M83. Analysis of the full sample of galaxies will provide strong constraints on models of galaxy formation.

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